Date: 20th September 2021
Our Ref No.: TJ/UT1/OUT-08

To,
Doosan Heavy Industries & Construction Co., Ltd.
Mr. Youngsoo Son– Project Manager
465 Gangnam-daero, Seocho-gu, Seoul, Korea (06611)

Contract Reference: Engineering, Procurement and Construction Contract between Nepal Water And Energy Development Company Private Limited (NWEDC) and Doosan Heavy Industries & Construction Co. Ltd for the Engineering, Procurement and Construction (EPC) for the 216 MW Hydropower Plant at Upper Trishuli -1, Nepal

Subject: Submission of Review Note on Excavation and Initial Support Drawings of Investigation Tunnel for Powerhouse

References:

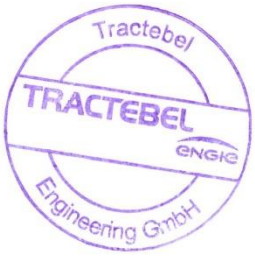
1. Document No. UT1-C-385-CVL-DC-65001 dated 19th August 2021
2. Drawing No.: UT1-C-385-CVL-DG-65001 dated 1st September 2021
3. Drawing No.: UT1-C-385-CVL-DG-65002 dated 1st September 2021

Dear Sir,

Reference is made to the above No.1, 2 and 3 received with transmittal No. UT1-HEP-DHI-D-0038 dated 1st September 2021, regarding excavation and initial support drawings of investigation tunnel for powerhouse.

Please find our comments in the Review Notes (RN-0009, RN-0010, and RN-0011) enclosed herewith this letter.

Sincerely,



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Mr. Carsten GUNTERMANN
Project Manager (CRE)

Enclosure:
1. Review Notes (RN-0009, RN-0010, and RN-0011)

UPPER TRISHULI-1 HEP (216MW)			
Client	**Nepal Water and Energy Development Company Private Limited**		
Owner's Engineer	**Tractebel Engineering GmbH / Jade Consult**		
REVIEW NOTE			
Contractor	**Doosan Heavy Industries & Construction Co., Ltd.**		
Title of the Document	Surrounding Rock Stability Calculation of Investigation Tunnel for Powerhouse		
Document No.	UT1-C-385-CVL-DC-65001	Revision	A
Date of Documents	19.08.2021	Received Date	01.09.2021
Transmittal Form No.	UT1-HEP-DHI-D-0038		
Previous Review Date/Status	N/A	Prev. Review Note No.	N/A
Review Note No.	**RN-0009**	**Present Review Date**	**20.09.2021**
		Present Review Status	**RR**
A: Approved AC: Approved with Comments RR: Returned for Resubmission			

Comments

The submitted report is similar structured and of similar quality as the Calculation Report for The Adit No. 3, which was responded with the Review Note RN-006, dated 17. August 2021.

It appears to be difficult for the Designer to do the calculations as required and to set up the Calculation Report accordingly. Therefore, within this review an appropriate approach in the calculations is suggested and a structure of the report is recommended:

General

Introduction

Briefly describe in general the layout of the tunnel, one typical cross section, encountered geology/lithology, ground water conditions, maximum overburden thickness etc. No general project description is required.

Design Objectives

Describe design objectives of the calculations, which are (1) to generally confirm the stability of the tunnel during construction and (2) to confirm (or adjust) the previously suggested support measures in the construction drawings.

References

This chapter shall include <u>all</u> references used in this report, which are: Reports, Drawings, Standards-Codes-Guidelines, Publications/Papers, Internet Citations.

Theoretical Background of Calculations

Software

Brief description of Phase2-software

Modelling Conditions, Material Law, Constitutive Model

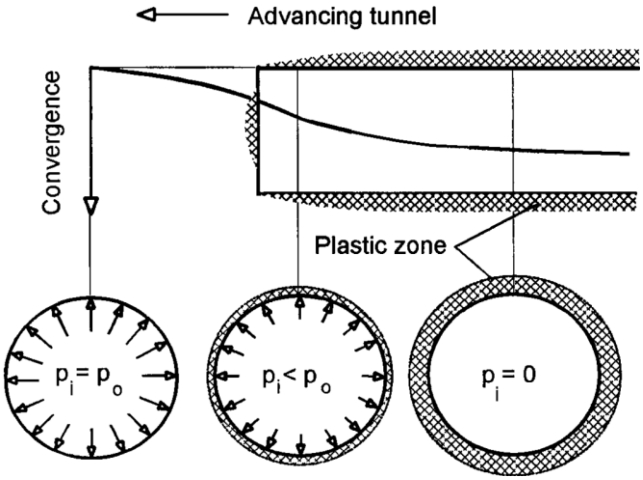
The modelling conditions are plane strain. The material law is elasto-plastic combined with strain-softening (for rock). The rock mass is modelled as a continuum, homogeneous and isotropic. The failure criteria is the Mohr-Coulomb failure criteria.

The Designer shall emphasise that such continuum model with homogeneous and isotropic material is a model, only, and does not necessarily reflect reality. In reality, displacements occur in blocky rock masses **always** along discontinuities (joints, foliation etc.), which leads to loosening of the rock mass. The determined plastic zone in the continuums model represents an area of the rock mass where rock blocks were displaced to each other (= loosening of rock mass). In reality, it does not represent an area where the material was subject to plastic flow, as in soil.

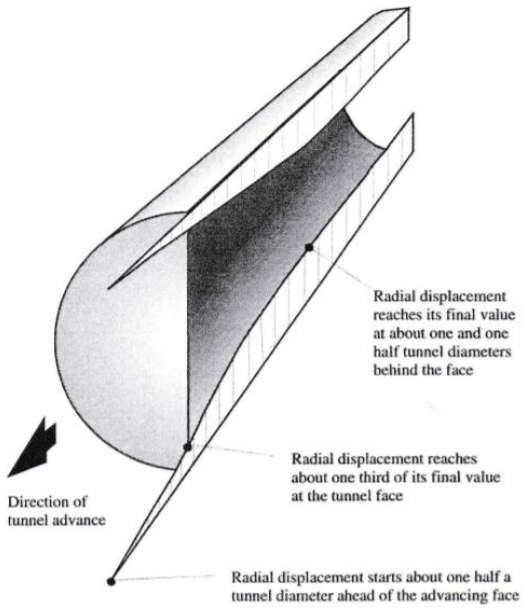
Calculation Methodology

The calculation method is suggested/recommended below. Text needs to be modified and individual stages of the modelling sequence need to be detailed in the Calculation Report.

The main problem for the modeller is generally to determine the ratio of in-situ stresses, which the support needs to carry after installation and loading. As there is already deformation ahead of the tunnel (= before support can be installed), there is also stress release. This is shown very schematically in the figure below. Far ahead of the tunnel face there is the *in-situ stress* p_0 equivalent to the stress p_i in the (future) tunnel (means $p_i = p_0$). This situation changes gradually when the tunnel is advancing until – for an unsupported tunnel – there is no more "supporting action" of the tunnel face (means $p_i = 0$). As the displacements cause in the blocky jointed rock mass disturbance and loosening, even being only a few millimetres, instability/collapse may occur in practice. **Therefore, systematic support is practically always required in tunnels, even when theoretical calculations and continuum models reveal that the tunnel is stable without support.** In other words, the primary function of the support is to control inward displacements and hence, to prevent loosening and block falls into the tunnel, and collapses (rare exceptions are tunnels in massive Class I rock).



In modelling of the advance of a tunnel and support installation most realistic and simple, it is firstly required to quantify, with the "Vlachopoulos and Diederichs Equations", the displacements along a longitudinal tunnel profile. The tunnel displacement profiles for the roof and the invert of a tunnel are shown schematically in the figure below.


Radial displacement reaches its final value at about one and one half tunnel diameters behind the face
Radial displacement reaches about one third of its final value at the tunnel face
Direction of tunnel advance
Radial displacement starts about one half a tunnel diameter ahead of the advancing face

With these analytical equations it is possible to estimate the amount of displacements at the specified location of support installation, if the plastic radius and displacement far from the tunnel face are known. Therefore, to get the displacements and the radius of the plastic zone far away from the tunnel face (where $p_i = 0$), it is necessary to calculate numerically with Phase2 the tunnel without support, first.

With the determined displacement profile along the tunnel and a given location of support installation (for example 1 m behind the face), the modeller selects the corresponding deformation (for example 30 mm).

In the next step the tunnel advance is modelled in Phase2 by reducing the deformation modulus of the material (elements) in the future tunnel until the corresponding deformation is reached (here 30 mm), when support is installed (here 1 m behind the tunnel face). The modeller installs now the support in the model. The deformation modulus of the elements is then reduced to 0 by deleting the elements in the tunnel. Further numerical calculation leads to loading of the support, most realistically.

The procedure suggested above can be studied with an example from the internet:

https://www.rocscience.com/help/rs2/tutorials/rs2__3d_tunnel_simulation.htm

Reference: Vlachopoulos, N. & Diederichs, M.S. (2009): Improved Longitudinal Displacement Profiles for Convergence Confinement Analysis of Deep Tunnels.- Rock Mechanics and Rock Engineering 42(2):131-146, April 2009. Freely downloadable on internet.

Materials

Rock Mass Properties

The following rock properties need to be listed for all six rock classes:

- Unit weight γ [kN/m^3]
- Uniaxial compressive strength (UCS) of intact rock, σ_c [MPa], (this is generally the same for all rock classes).
- Modulus of elasticity of rock mass E_m [GPa]
- Poisson´s ratio of rock mass n [-]
- Peak friction angle of rock mass ϕ_{peak} [°]
- Peak cohesion of rock mass c_{peak} [MPa]
- Residual friction angle of rock mass ϕ_{res} [°])*
- Residual cohesion of rock mass c_{res} [MPa])**
- Uniaxial compressive strength of rock mass, UCS σ_{crm} [MPa])***
- Tensile strength of rock mass σ_{trm} [MPa])****

)* 80% of ϕ_{peak} is acceptable

** 50% of c_{peak} is acceptable

)*** $\sigma_{crm} = 2\, c_{peak} \cos\phi_{peak} / (1-\sin\phi_{peak})$

)**** 10% of σ_{crm} is acceptable

Improved Rock Mass Properties

The reviewer thinks that with high probability the suggested support for Class V will not be able to carry the load and will be over-stressed. In such cases, the respective ground improvement measures (such as cement grouting) and additional support measures (spiles) need to be considered in the model. This can be done by reasonably assuming improved/increased rock mass parameters around the tunnel. The respective parameters need to be reliably estimated and listed, which will then be used in the model to simulate ground improvement and additional supportive measures.

The respective rock properties need to be justified. The area around the tunnel where these properties shall be applied needs also be defined reasonably.

Rock Dowels

- Type
- Diameter
- Modulus of elasticity
- Tensile Load (allowable):
- Residual tensile load:

Steel Ribs / Lattice Girder

- Type
- Height
- Width
- Unit weight
- Thickness
- Area
- Moment of inertia
- Young's modulus
- Poisson's ratio
- Compressive Strength
- Tensile Strength

For lattice girder required input parameters for Phase2 need to be specified.

Shotcrete

- Compressive Strength
- Tensile Strength
- Poisson's ratio
- Young Modulus

Tunnel Support

Tunnel Support per Excavation Class

Specify the support for each excavation class. Provide table and include location of installation of support behind the tunnel face.

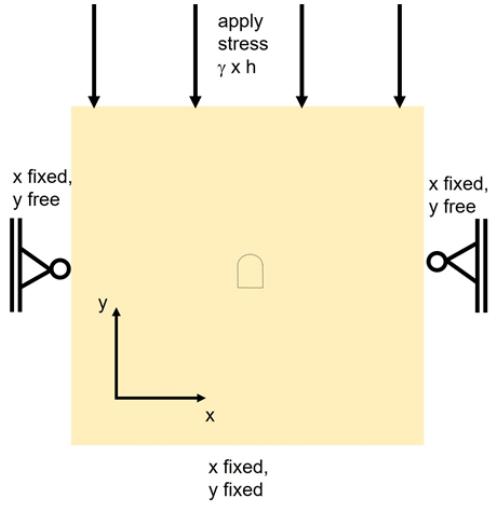
Support Safety Factor

Safety Factors for the individual support elements need to be listed following the contractual requirements.

Model Set-up, Boundary and Loading Conditions, Stress Initiation

The model should extend at least six tunnel diameters from the tunnel. For simplicity – and to speed up calculations - it is not required to extend the model to the surface, but to apply respective stresses at the model's upper boundary.

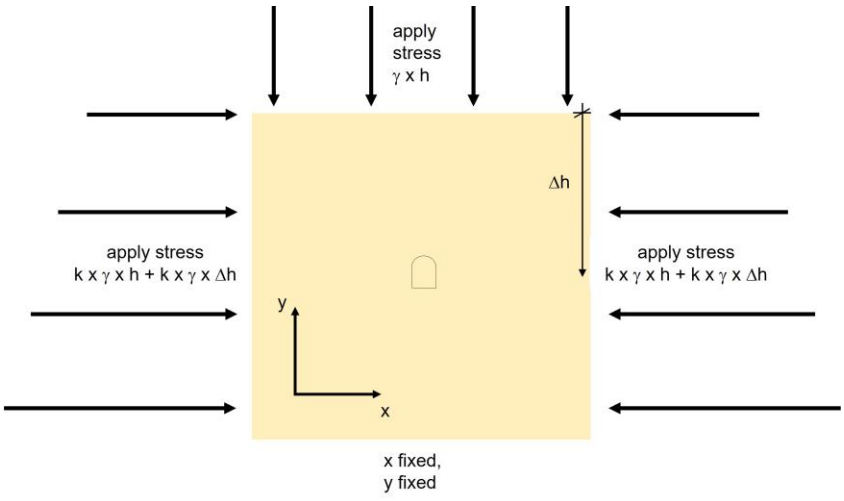
For the case of gravitational loading, only, boundary and loading conditions to be set as shown below. This applies for tunnels in the UT1-Project that are oriented NNE-SSW (+/- 45°), as NNE-SSW is generally orientation of the maximum horizontal stress σ_H in the Upper Himalaya, which is in the plane-strain Phase2-model the ("irrelevant") out-of-plane stress. Hence, initial stress conditions in the model can be calculated by gravitational loading. Alternatively, the boundary conditions shall be applied as in the sketch and initial stress conditions can be initiated in the model accordingly.



γ = unit weight of rock

h = overburden thickness (maximum overburden thickness of the tunnel for all rock classes)

For all other tunnels in the project that are aligned differently, increased horizontal stresses must be modelled as shown in the sketch below.



γ = unit weight of rock

h = overburden thickness

k = maximum horizontal stresses σ_H / vertical stress σ_v

For tunnels where no stress measurements are available or applicable (e.g. away from the Powerhouse), a reasonable assumption for tunnels in the Upper Himalaya is k = 1.5.

Initial stress conditions in the model can be calculated with Phase2 or, more convenient, they are initiated.

Tunnel Modelling and Results

The modelling shall follow the sequence as shown below and the respective results need to be displayed in the respective sub-chapters for each rock class:

- **Model Set-up**
- **Calculations without Tunnel Support** (this is to determine the extent of the plastic zone and maximum displacements in the tunnel roof)
- **Analytical calculation of the Longitudinal Deformation Profile in the Tunnel Roof**
- **Selection of Displacement Values at Support Installation and Modelling of Tunnel Displacements at Support Installation**
- **Modelling of Loading of the Support** (by finally removing the elements in the tunnel)

Wedge Analysis

Potential unstable rock wedges need to be identified using rigid body limit equilibrium method. This is to determine the size of wedges, their location in the sidewalls or the roof, and the required stability measures.

Discontinuity Input Data

The prevailing discontinuities need to be defined by their orientation (dip/dip direction), their persistence, their spacing (= 1/frequency) and their mechanical properties (joint cohesion c_j and joint friction angle ϕ_j). In case no laboratory data is available, the strength parameters need to be reliably estimated.

Stability Calculations

It is suggested to use the program UNWEDGE.

Wedge Analysis Results and required Support Measures.

The results need to be comprehensively presented and discussed with respect to required support measures.

Conclusions and Recommendations

The results of all calculations need to be summarized and conclusions drawn. Recommendations for variation of the support, if any, need to be shown.

DISCLAIMER

Any approval will not release the Contractor from any of his obligations under the Contract.

Dr. Ulrich Glawe

(Signature)